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(54) **Microreactor for Reaction Agents in the Form of a Suspension**

(57) The invention concerns a microreactor for conducting chemical reactions whereby the conduct of the chemical process takes place in horizontal spaces that are formed by two or more superimposed plates or laminae, characterized by the fact that these plates or laminae are structured in such a manner that reactions can be conducted in which at least one reactant occurs in the form of a suspension.

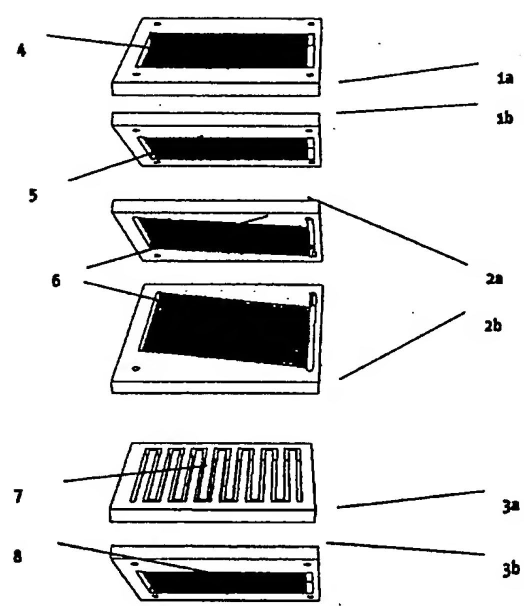


Fig. 1

Description

[0001] The invention concerns a microreactor for conducting chemical reactions, whereby the conduct of the chemical process takes place in horizontal spaces that are formed by two or more plates or laminae stacked one above the other, whereby these plates or laminae are structured in such a manner that reactions can be conducted in which at least one of the reactants occurs in the form of a suspension.

[0002] Such a microreactor represents a miniaturized reaction system for industrial processing and chemical processing technology. A microreactor of this conceptual type is known for example from EP 0 688 242 B1 and US 5,811,062. These microreactors are made of many stacked small plates that are connected with each other, upon the surfaces of which there are micromechanically produced structures that form reaction spaces in their reciprocal effect, in order to conduct the desired chemical reactions. There is at least one channel leading through the system, which has an inlet and outlet connection.

[0003] Microreactors that are known thus far are not suitable for reactions in which solid materials are fed or occur that are in suspended form, since these materials can block up the microchannels.

[0004] The invention meets the goal of making a microreactor system that makes it possible to accommodate the feed and / or occurrence of reaction agents that occur in the form of a suspension. The microreactor should be able to maintain an exact temperature control of the reaction process, ensure a rapid mixing of the reaction agents, and reduce the potential danger of strongly exothermic or explodable reactions due to the small internal volume. The microreactor also should be economical to manufacture in order to be used if needed in a single-way system. The different function modules (heat exchanger, mixer = reactor, dwell paths, condensers, distillation and / or extraction units) can be manufactured in a standardized manner independent of the given reaction type that is to be conducted. By selecting the liquid feed openings these standard functional modules can be combined as needed, and permanently or temporarily connected to each other.

[0005] The goal is met based on the characteristics of claim 1 and is given form and further substance by the other characteristics of the subordinate claims. To give details, functional modules are formed that can be suitably assembled together with respect to the chemical process reaction to be conducted, and they can be connected with each other. The modular construction approach makes it possible to achieve a simple modification to the given changing conditions as they occur, in that individual elements of the microreactor can be switched in and out, in order to satisfy the requirements of the reaction that has been selected, or when the expected results do not occur, or when there are breakdowns.

[0006] By exchanging the components, the feed of liquid can finally be dimensioned in such a manner that an improved temperature control of the reaction is established, or so that a higher selectivity and a decrease in observed undesirable reaction by-products is observed, i.e., one obtains the desired reaction product with fewer impurities.

[0007] The concept of suspension noted above and from here on denotes a system of several phases in which one is continuous and at least one is finely distributed. As a rule, such suspensions are systems in which at least one finely distributed solid phase occurs in a liquid, continuous phase.

[0008] The concept of reactant includes mixtures or pure materials that contain educts, i.e., reactants or products.

[0009] The forms of the microreactor according to this invention are not critical in themselves. The individual plates or laminae can be present in any geometric shape. Preferably they are round, oval, square, or rectangular. Rectangular plates are especially preferred with respect to their positioning characteristics.

[0010] Essential for the microreactor of this invention are the dimensions of the microstructured areas in which the reaction agents are present in the form of suspensions.

[0011] These areas must be selected at sizes large enough so that the particles of the finely distributed

phase can pass through without any problem, so that no blockages occur. The smallest clear width of the microstructures should be approximately 10 times the diameter of the largest particle of the finely distributed phase. Furthermore, care must be exercised to provide an appropriate geometric shape, so that no dead water zones occur, such as blind alleys or sharp corners, for example, in which the particles of the finely distributed phase can precipitate. Preferably the reaction agents will be conducted in a continuous path with rounded corners.

[0012] On the other hand, the structures must be small enough in order to exploit the natural advantages of microreaction technology, namely excellent heat control, laminar flow, diffusive mixing, and small internal volume. Consequently, the structures have a size smaller than 1000 μm, preferably smaller than 800 μm, in particular smaller than 600 μm.

[0013] While the individual process methodological operations proceed from the individual functional modules, these should be connected to each other via vertical channels in order to treat further the reactants from one level to the next. The function modules themselves contain horizontal channels and spaces that are tailored to the desired process step. Between the channels and the spaces there are separation barriers that are sealed based on the pressure exerted on the stack of functional modules. Thus it is established that the vertical channels are responsible for the input and output of the reactants and accessory media, while the reactions themselves take place in the horizontally located spaces.

[0014] Materials that may be considered for the plates or laminae include metals (stainless steel), glass, ceramic, semiconductor material, particularly that based on silica, as well as synthetic materials. The selection of these work materials or combinations of these is determined by the application that is provided. Stainless steel is especially preferred.

[0015] During the conduct of the chemical process, various parameters must be observed. Therefore the insertion of sensors into the microreactor is provided for, in particular sensors for capturing the temperature, pressure, and in some cases the flow rate and volume flow. The sensors are connected with control circuits in order to be able to control and manage the course of the reaction.

[0016] The invention is described based on the drawing. Figure 1 shows a microreactor in schematic, exploded representation.

[0017] Between the cover plate (not shown) and a base plate (not shown) there are a number of functional modules 1, 2, and 3, all of which are held by the assembly under pressure or are rigidly connected, in order to compress the sealing surfaces between the modules. Each functional module 1, 2, 3 contains a module half 1a, 1b, or 2a, 2b, or 3a, 3b. In the cover plate there are fluid connections arranged. From there, horizontal channels lead to functional spaces 4, 5, 6,7, and 8, which as a rule contain a channel system or a labyrinth system. The reaction channels of these reaction spaces run in general diagonally or transverse to each other.

[0018] In the application example shown, it is assumed that the functional module 1a/1b represents a heat exchanger half, which consists of a heat exchanger half 4 for cooling and / or heating medium and a heat exchanger half 5 for conducting the reaction. The functional module 2a / 2b would be a mixer half 6 for conducting a reaction partner A and a mixer half 6 for conducting a reaction partner B. The functional module 3a/3b represents a dwell path that consists of a dwell path half 7 for the reaction product and a dwell path half 8 for a cooling and / or heating medium.

[0019] The microstructures in the area of the heat exchanger 4 and 8 have a channel width of 100 to 800 μm, preferably 300 to 600 μm, in particular 400 to 500 μm, and a channel depth of 100 to 400 μm, preferably 200 to 300 μm, in particular 225 to 275 μm. Since in these ranges no suspensions occur, the type of fluid feed is not a problem. To achieve an efficient heat transfer, the wall thickness of the separator barrier between the heat carrier and the reaction medium is smaller than about 800 μm as a rule, preferably smaller than about 400 μm. Consequently, the plates as a rule have a total thickness of from 500 to 1000 μm.

[0020] The microstructures in the area of the reaction media 5, 6, and 7 have as a rule a channel width of 400 to 1000 μm, preferably 500 to 700 μm, in particular 550 to 650 μm. and a channel depth of 200 to 800 μm, preferably 400 to 600 μm, in particular 450 to 550 μm.

[0021] The individual plates or laminae can be held together by screw connections or pressure clamps if one is dealing with a soluble compound. One may also use welding, bonding, gluing, soldering, or riveting if such a reaction system is no longer to be altered after assembly.

[0022] Yet another object of the invention is a process for manufacturing a microreactor according to this invention for conducting chemical reactions, using the following steps:

a) Production of many plates or laminae, the surfaces of which are structured by micro technology or precision finishing technology in such a manner that they are capable of handling reaction media that occur as suspensions

b) Stacking of individual plates or laminae in an appropriate sequence and orientation; and

c) Sealing assemblage of the stack using pressure or bonding techniques.

[0023] The structuring in step a) can result from etching, laser cutting or water stream cutting and drilling, punching and stamping, milling, shaping and boring, injection molding and sintering, as well as spark erosion and combinations of these.

[0024] Preferably the metal sheets of the individual plates or laminae are produced by etching, laser cutting and / or laser drilling.

[0025] The layers must be stacked one over the other in such a manner that on the hand fluid feeds and separation walls are maintained completely; on the other hand, a complete water-tight and gas-tight joint should occur between the individual layers.

[0026] If the surface roughness lies in the area of 1 μm or less and the surface is absolutely free of scratches, is clean, and is free of grease, then it is possible to achieve a gas-tight superimposition of the sheets by applying an even mechanical pressure onto the stack.

[0027] What is essential for this arrangement is that the remaining fissure be smaller than 1 μm. This produces such a high flow resistance between the plates that although fluids can enter slightly into the fissure, no leaks occur, since no flow, as can happen in capillaries, can arise.

[0028] The material from which the functional modules consist depends primarily on the materials to be treated and the chemical processes. In general, materials that are suitable for chemistry work come into consideration, including stainless steel, glass, ceramic, synthetic material, and semiconductor material, as well as combinations of these materials.

[0029] As a whole, this invention makes available a modular constructed, miniaturized reaction system that makes it possible to integrate the various functions that are significant for conducting the process and that based on its microstructure is suitable for conducting reactions in which at least one reaction medium occurs in the form of a suspension. Among these functions one understands the feed of reactants, their preprocessing heat treatment, the mixing of reactants under controlled thermal conditions, and intermediate thermal treatment, as well as a postprocessing dwell time and the withdrawal of the reaction product into suitable containers. The microstructure inherent in the invention includes the sizing of the microchannels and the avoidance of dead water zones.

[0030] Also, the object of the invention is consequently a method for execution of chemical reactions, whereby one or more chemical reactants in gaseous form, liquid, and / or suspended form are mixed in two or more horizontal spaces and brought into reaction with formation of a liquid and / or suspended reaction product, whereby at least one reaction medium is present in the form of a suspension.

[0031] The concept of "liquid form" includes both the reactants that themselves occur in a liquid

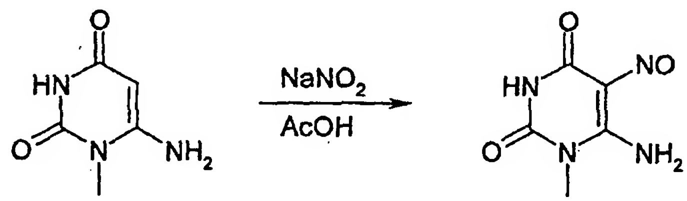
aggregate state as well as reactants that are introduced into a mixture with a liquid diluting agent. In one form of execution that is especially preferred, at least two reactants are brought into reaction in the presence of at least one diluent in a microreactor according to the invention.

[0032] To make it easier to understand this invention, the following illustrative examples for possible reaction types are presented. This invention is not limited to these specific forms of execution, but rather encompasses the full extent of the patent claims.

[0033] Examples for reactions in accordance with this invention are conversions of uracil with sodium nitrite and cholesterol with bromine.

Example 1

[0034]

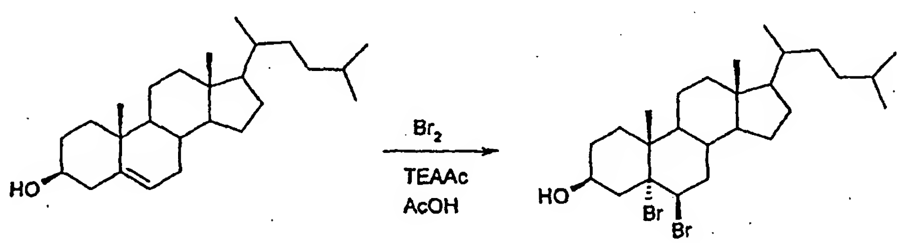


1 2

[0035] Using a glass vessel, dissolve 2.00 g of educt 1, 1.62 g of sodium nitrite, and 4.00 g NaOH of water and fill to 100 ml. In a second vessel, dissolve 10.21 g of glacial acetic acid with water and fill to 100 ml. These solutions are pumped using calibrated piston pumps, each with a flow rate of 1 ml/min into the educt inlets of the microreactor. A thermostat is connected to the heat exchanger-circulator of the microreactor, which establishes the desired reaction temperatures of 50 C. The product suspension exiting the reactor is collected in a retort, drawn off after cooling to room temperature to complete crystallization, washed neutral with water, and dried. Product 2 is obtained at a yield of 85 percent.

Example 2

[0036]



3 4

[0037] Put 38.7 g of cholesterol 3 and 15.5 ml of a 1 molar triethylaminacetate solution in water free

aggregate state as well as reactants that are introduced into a mixture with a liquid diluting agent. In one form of execution that is especially preferred, at least two reactants are brought into reaction in the presence of at least one diluent in a microreactor according to the invention.

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Example 1

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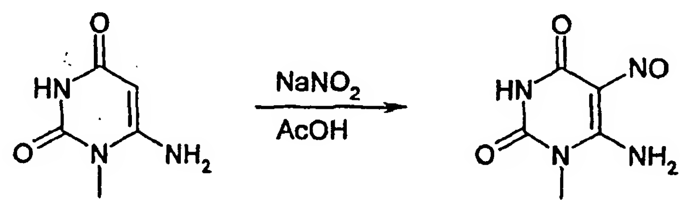

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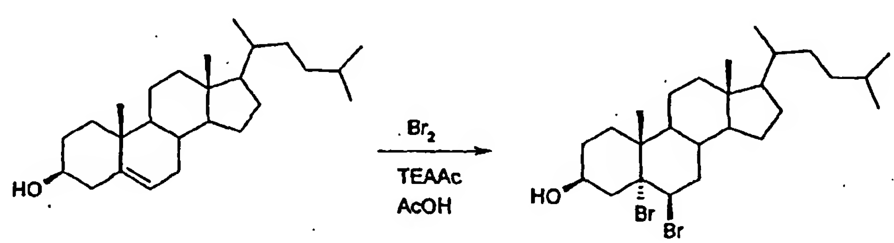

3 4

[0037] Put 38.7 g of cholesterol 3 and 15.5 ml of a 1 molar triethylaminacetate solution in water-free

diethylether and fill with water-free diethylether to 300 ml. Dissolve 16.0 g of bromine in 150 ml glacial acetic acid. Using calibrated piston pumps, the educt solution is pumped at a flow rate of 6 ml/min and the bromine solution is pumped at a flow rate of 3 ml/min into the given educt inlets of the microreactor. A thermostat is connected to the heat exchanger-circulator of the microreactor, which maintains the desired reaction temperatures at 30 C. The product suspensions exiting the reactor are collected in a retort, drawn off at room temperature, washed with cold glacial acetic acid until the wash is colorless, and dried. Product 4 is obtained at a yield of 70 percent.

Patent Claims

1. Microreactor for the conduct of chemical reactions, whereby the conduct of the chemical process occurs in horizontal spaces that are formed by two or more plates or laminae stacked over each other, characterized by the fact that these plates or laminae are structured in such a manner that reactions can be conducted in which at least one of the reaction media occurs in the form of a suspension.

2. Microreactor in accordance with claim 1, whereby the plates or laminae (1a, 1b, 2a, 2b, 3a, 3b) are stacked over each other in such a manner that channels and spaces that extend horizontally (4, 5, 6, 7, 8) are formed for conducting the chemical process, whereby functional modules are formed in which individual physical or chemical processes can be conducted, characterized by the fact that the microstructures in the area of the reaction media (5, 6, and 7) have channel widths of 400 to 1000 μm, preferably 500 to 700 μm, in particular 550 to 650 μm, have channel depths of 200 to 800 μm, preferably 400 to 600 μm, in particular 450 to 550 μm, and have only geometries that do not form dead water zones.

3. Microreactor in accordance with claim 1 or 2, characterized by the fact that the microstructures in the area of heat exchanger media (4 and 8) have channel widths of 100 to 800 μm, preferably 300 to 600 μm, in particular 400 to 600 μm and channel depths of 100 to 400 μm, preferably 200 to 300 μm, in particular 225 to 275 μm.

4. Microreactor in accordance with claims 1 through 3, characterized by the fact that the reaction media are fed in a continuous path with rounded edges.

5. Microreactor in accordance with claims 1 through 4, characterized by the fact that the conduct of the process includes the following steps:

   - feed of reactants
   - their pre-processing heat treatment
   - mixing of the reactants under thermally controlled conditions
   - a post-processing dwell time
   - collection of the one or more reaction products.

6. Microreactor in accordance with claims 1 through 5, characterized by the fact that sensors for control of process parameters, such as temperature, pressure, flow rate, volume or mass flow, pH, are installed either in the individual functional modules or outside them.

7. Microreactor in accordance with claims 1 through 6, characterized by the fact that control circuits are provided that, based on measured parameters, control the material flow in the fluid connections as well as the energy input and output with respect to the functional modules.

8. Microreactor in accordance with claims 1 through 7, characterized by the fact that mixers, heat exchangers, dwell spaces, filters, condensers, distillation columns, or extraction columns are provided as integrated functional modules.

9. Process for production of a microreactor for conducting chemical reactions in accordance with one of the claims 1 through 8, which has the following steps:

(a) production of many plates or laminae, the surfaces of which are treated by microtechnology or precision engineering technology such that they have sealing zones and — together with the surfaces of another plate or lamina — horizontal reaction spaces

(b) stacking of individual plates or laminae in a suitable sequence and orientation, and

(c) sealing compression or rigid joining of the individual plates or laminae.

10. Process for the conduct of chemical reactions, characterized by the fact that one or more chemical reactants in gas form and / or liquid form and / or suspended form are mixed in the horizontal space formed by two or more super-imposed plates or laminae of a microreactor, and reacted under the formation of a liquid, dissolved, or suspended reaction product, characterized by the fact that at least one reaction medium occurs in the form of a suspension.

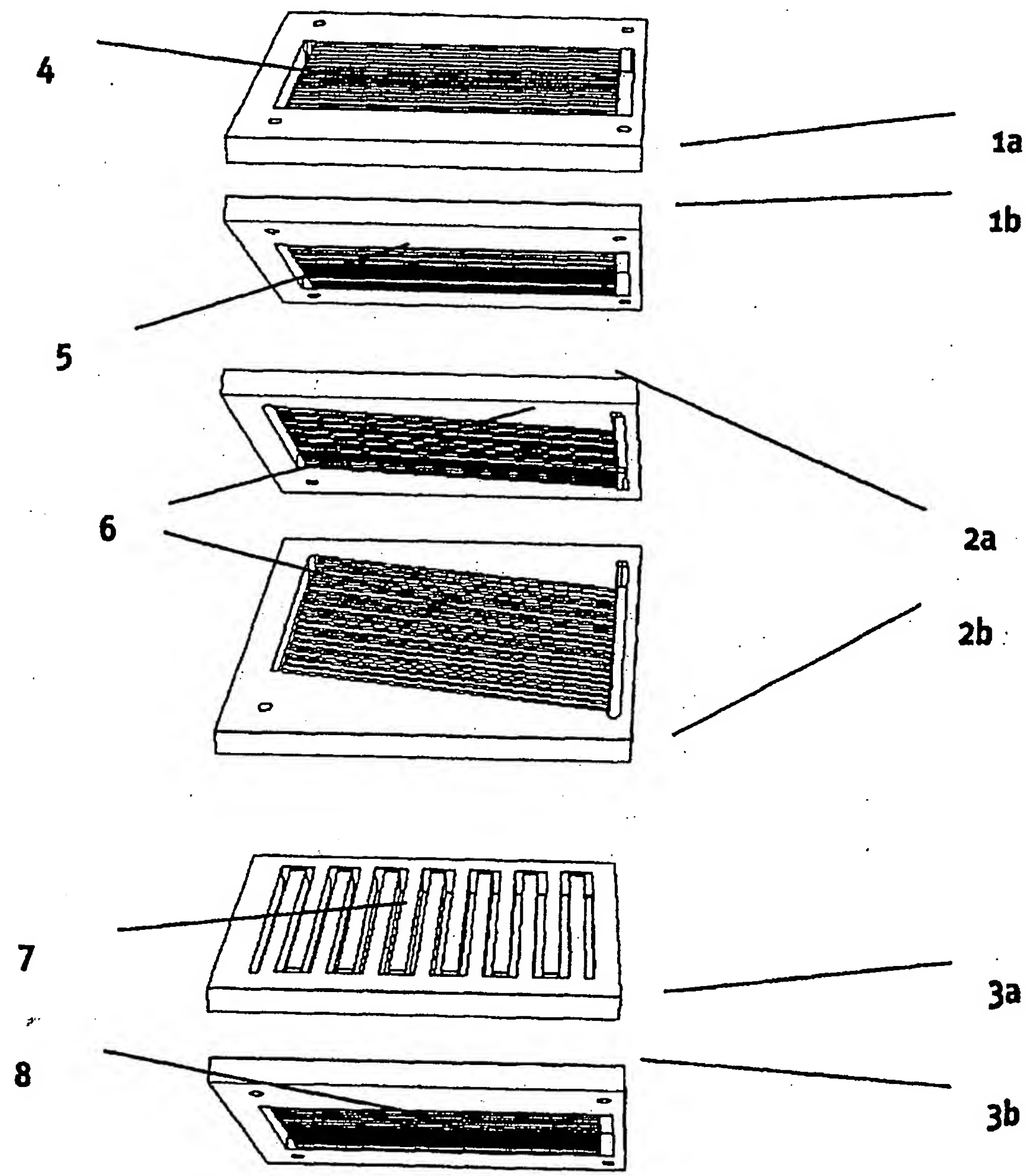

Fig. 1